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Photoluminescence of InAs/GaAs quantum dots under hydrostatic pressure

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Abstract. The baric dependencies (0–20 kbar) of luminescence spectra (77 K) of InAs quantum dots have been investigated. InAs quantum dots on vicinal substrates GaAs at misorientation angle 3[001], 7[001] and 7[0$\bar{1}$1] were grown. At $P = 0$ in the luminescence spectra a set of lines 1.235, 1.290, 1.343 eV of quantum dots of different sizes with base lengths 8–9 nm was observed. The dependence of baric coefficients on size of quantum dot was found out.

Introduction

Now the physical properties of quantum dots are researched very intensively, particularly of the quantum dots placed in crystal matrices. The molecular beam epitaxy method allows to obtain the structures with given parameters. The theory of optical transitions leading to a satisfactory correspondence to experimental properties has been developed. The theory describes a blue quantum size shift, however the structure excited states has not sorted out. The experiments with the using of high hydrostatic pressure indicated to the important role of a matrix in forming of excited states, however there remains a lot indistinct moments.

1. Experimental

The baric dependencies of luminescence spectra (77 K) of samples with InAs quantum dots, grown on vicinal substrates GaAs at misorientation angle 3[001], 7[001], 7[0$\bar{1}$1] have been investigated.

The structures consist of the InAs quantum dots confined from both sides with wide-gap GaAs and $Al_{0.25}Ga_{0.75}As$/GaAs superlattices (5 pairs, 2 nm/2 nm each). Singular substrates GaAs [100], disoriented on 3°–7° were used. For better homogeneity of temperature field of the sample and univormity of molecular flows on substrate surface the samples were pasted using In to one holds side-side.

The luminescence spectra were excited by He–Ne laser at power 1 W/cm^2. The studies were conducted in the range from 0 to 20 kbar in the high-pressure camera with anvils of laicosapfire. The mixture of wood-spirit and ethyl alcohol in the ratio of 1:10 was used for transmission of the pressure to samples. Magnitude of hydrostatic pressure was determined from displacement of R1-luminescense line of ruby, placed in driving volume of camera in the immediate vicinity of the sample under study. Samples were prepared in form of parallel-plane plates of sizes 0.5 × 0.5 mm^2 and thickness 0.05 mm.

2. Results

At $P = 0$ in the luminescence spectra of all studied samples a set of lines at energies 1.235, 1.290, 1.343 and 1.408 eV as well as lines of free exciton of the substrate GaAs at 1.51 eV was observed. The individual components of the spectrum correspond to the emission of quantum dots of different sites with base lengths, varying within the 8–9 nm.

With increasing hydrostatic pressure the short-wave shift of all spectral peculiarities was observed. Simultaneously the increase of the energy extent of the emission spectrum with relative development of contribution of high energy components place.

At $P > 5$ kbar an additional peculiarity-WL, absent at $P = 0$, arose. The emission spectra of one samples, having the most developed structure 7[001], at different hydrostatic shifts are given in Fig. 1(a). In Fig. 1(b) two spectra at $P = 0$ and $P = 10$ kbar, superimposed at energy of free exciton in GaAs are given for comparison and illustration of the change of energy distances between the peculiarities.

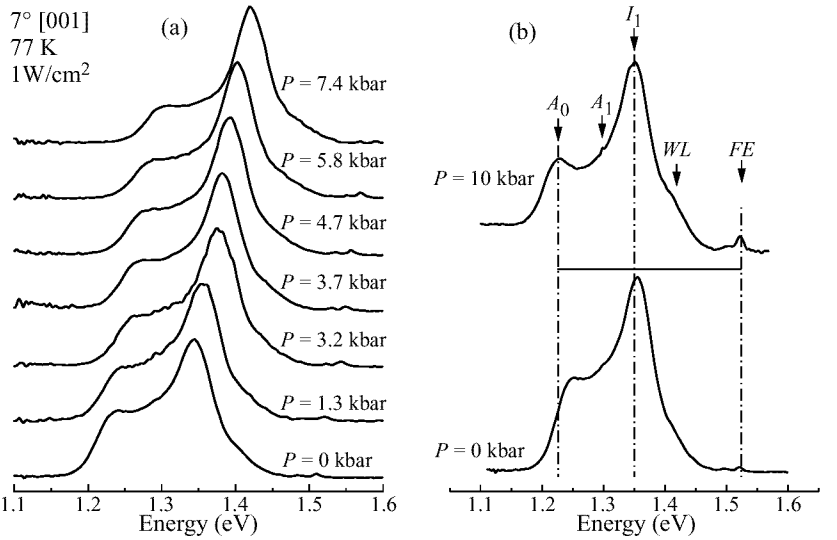

Fig. 1. (a) The emission spectra of 7[001] samples at different hydrostatic pressure and $T = 77$ K. (b) The spectra at $P = 0$ and $P = 10$ kbar superimposed at energy of free exciton in GaAs. The power of He–Ne laser is 1 W/cm^2, $T = 77$ K.

The dependencies of energy position of the peculiarities on hydrostatic pressure and dependence of energy interval between the emission lines of quantum dots of different sizes and luminescence line of free exciton of the substrate are shown in Fig. 2(a) and Fig. 2(b). Figure 2(b) allows us to determine the magnitude of hydrostatic shift from the known meaning of baric coefficient of substance 10.2 meV/kbar (10.7 meV/kbar [4]) precisely.

3. Discussion

In literature there is a numbers of work [2–4] on investigations of the influence of hydrostatic pressure on luminescence spectra of quantum dots InAs/GaAs. Mainly the authors were interested in the range of high hydrostatic pressures $P > 40$ kbar at which the transformation of emission spectra took place in consequence of change of band structure of GaAs crystals. The observed by us dependence of hydrostatic shift magnitude on a size of pyramidal quantum dots InAs was not found out earlier. We suppose that the revealed effect

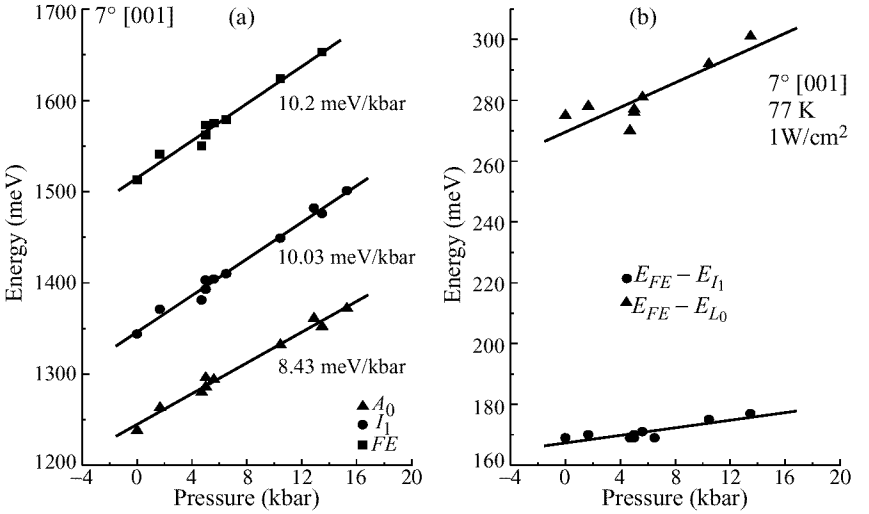

Fig. 2. (a) The baric dependencies of energy of quantum dots A_0, I_1 and of free exciton of substrate GaAs-FE. (b) The baric dependencies of energy interval between emission lines of free exciton of substrate GaAs and quantum dots of different sizes A_0 and I_1.

due to the influence of GaAs matrix on a spectrum of quantum dots InAs too. Indeed it is known from the theory that in parallel with the size effect the internal hydrostatic pressure as well as size effect contributes to the forming of band structure of pyramidal quantum dots [5]. It is caused by the difference between lattice constants of InAs and GaAs and depends on a length of pyramid base. It probably causes the observed in this work dependence of the baric coefficients on size of quantum dot. The difference of energy structures of pyramidal quantum dots InAs in GaAs and spherical dots InAs in polymer matrices [6] points to the possibility of such interpretation. The energies of the transitions InAs in GaAs crystals are more then those in polymer matrices by value of orders 0.3 eV owing to internal tensions.

4. Conclusion

In present paper the baric dependencies the of the luminescence spectra of InAs quantum dots, grown on vicinal substrates GaAs have been investigated. The dependencies of the baric coefficients on size of quantum dots has been found out. The possible interpretation of this effect has been given. In future for the suggestion it is proposed to carry out the direct calculation of the dependence of baric coefficient on nanocrystals size on the basic of the theory [5].

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